NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 389

c. 3

THE EFFECT OF SMALL ANGLES OF YAW AND PITCH ON THE CHARACTERISTICS OF AIRPLANE PROPELLERS

By HUGH B. FREEMAN

1931

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - Price 10 cents

AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp
Speed		km/h	k. p. h.	mi./hr.	m. p. h.
		m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/s^2 $= 32.1740$ ft./sec.^{2}

m, Mass $= \frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C. and 750 mm $= 0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m^3 $= 0.07651$ lb./ft.^{3}.

mk^2, Moment of inertia (indicate axis of the radius of gyration k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord.

$\frac{b^2}{S}$, Aspect ratio.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $= \frac{1}{2}\rho V^2$.

L, Lift, absolute coefficient $C_L = \frac{L}{qS}$

D, Drag, absolute coefficient $C_D = \frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o} = \frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$

R, Resultant force.

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting (relative to thrust line).

Q, Resultant moment.

Ω, Resultant angular velocity.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, at 15° C., the corresponding number is 234,000;

or for a model of 10 cm chord 40 m/s, the corresponding number is 274,000.

C_p, Center of pressure coefficient (ratio of distance of $c. p.$ from leading edge to chord length).

α, Angle of attack.

ϵ, Angle of downwash.

α_o, Angle of attack, infinite aspect ratio.

α_i, Angle of attack, induced.

α_a, Angle of attack, absolute.

(Measured from zero lift position.)

γ, Flight path angle.

REPORT No. 389

THE EFFECT OF SMALL ANGLES OF YAW AND PITCH ON THE CHARACTERISTICS OF AIRPLANE PROPELLERS

By HUGH B. FREEMAN
Langley Memorial Aeronautical Laboratory

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NAVY BUILDING, WASHINGTON, D. C.

(An independent Government establishment, created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight. Its membership was increased to 15 by act approved March 2, 1929 (Public, No. 908, 70th Congress). It consists of members who are appointed by the President, all of whom serve as such without compensation.)

EXECUTIVE COMMITTEE

REPORT No. 389

THE EFFECT OF SMALL ANGLES OF YAW AND PITCH ON THE CHARACTERISTICS OF AIRPLANE PROPELLERS

By Hugh B. Freeman

SUMMARY

The subject tests were carried out in the 20-foot wind tunnel of the National Advisory Committee for Aeronautics to determine the effect on the characteristics of a propeller of inclining the propeller axis at small angles to the relative wind. Tests were made of a full-scale propeller and fuselage combination at four angles of yaw (0°, +5°, +10°, and +15°), and of a model propeller, nacelle, and wing combination at five angles of pitch (−5°, 0°, +5°, +10°, and +15°).

The results of the full-scale tests of a propeller and fuselage, without a wing, show that the effect on the propeller performance is small. Similar results are shown by the model test data except that where the propeller is directly in front of the wing there is an appreciable decrease in effective thrust and propulsive efficiency with increase of angle of pitch.

INTRODUCTION

In the prediction of airplane performance it is usual to assume that the line of thrust of the propeller is parallel to the flight path. This condition exists, of course, for only one particular angle of attack of the airplane. For any other angle of attack, especially when climbing or flying horizontally at low speeds, the thrust line is inclined at an angle to the line of flight. Previous model propeller tests have shown that the reduction in thrust is negligible for small angles of pitch. (Reference 1.) Such tests have been made, however, with the propeller alone, so the conditions do not correspond to those found in practice, where the propeller usually operates in front of a body such as a fuselage, nacelle, or wing.

The object of the tests described in this report was to determine the effect of inclining the thrust line at small angles to the relative wind on the characteristics of a propeller operating in front of a body. Two series of tests were made. The first series consisted of yaw tests of a full-scale propeller and fuselage. It would have been desirable to change the angle of pitch instead of that of yaw, but this was not possible with the torque dynamometer available, since it would not function properly except when in a level position. However, for the propeller and fuselage, without a wing, it is obvious that changing the angle of yaw will cause a similar effect on the propeller performance to that caused by changing the angle of pitch. In the second series, a model propeller and nacelle were tested alone and in two positions relative to a wing, the combination being pitched at various angles. All the tests were made in the 20-foot tunnel of the National Advisory Committee for Aeronautics.

APPARATUS AND TESTS

The full-scale propeller and fuselage are shown mounted in the wind tunnel in Figure 1. The propeller was 9 feet in diameter and had two adjustable aluminum alloy blades. The curves for the blade form and pitch distribution are given in Figure 2. The propeller was driven by a 435-horsepower Curtiss D–12 engine mounted in an open-cockpit fuselage. A dynamometer for measuring the torque of the engine was also mounted in the fuselage. A description of this dynamometer, the thrust balance, and other wind-tunnel apparatus will be found in reference 3.

Tests were made at propeller pitch settings of 15.5° and 23.5° (at 0.75 radius) with the propeller axis yawed at 0°, 5°, 10°, and 15°. The method of conducting the tests was the same as that described in reference 2.

The method of supporting the model wing and nacelle in the wind tunnel is shown in Figure 3. The wing and nacelle pivoted about the top of the two wing supports, and the angle of pitch was changed by raising or lowering the end of the long sting extending in the rear of the wing. A 25-horsepower electric motor, for driving a 4-foot model propeller, was mounted in the nacelle. No means were available by which the torque of the motor could be measured directly; the motor torque was therefore calibrated, for a constant field excitation, using a Prony brake. Later the calibration was checked by means of a dynamometer. The wing was 15 feet 10 inches in span, 3 feet 2 inches in chord, and had a Clark Y airfoil section.

The 4-foot metal propeller used in the model tests was geometrically similar to the propeller used in the full-scale tests. It was first tested with the nacelle alone (fig. 4a), second with the nacelle above the

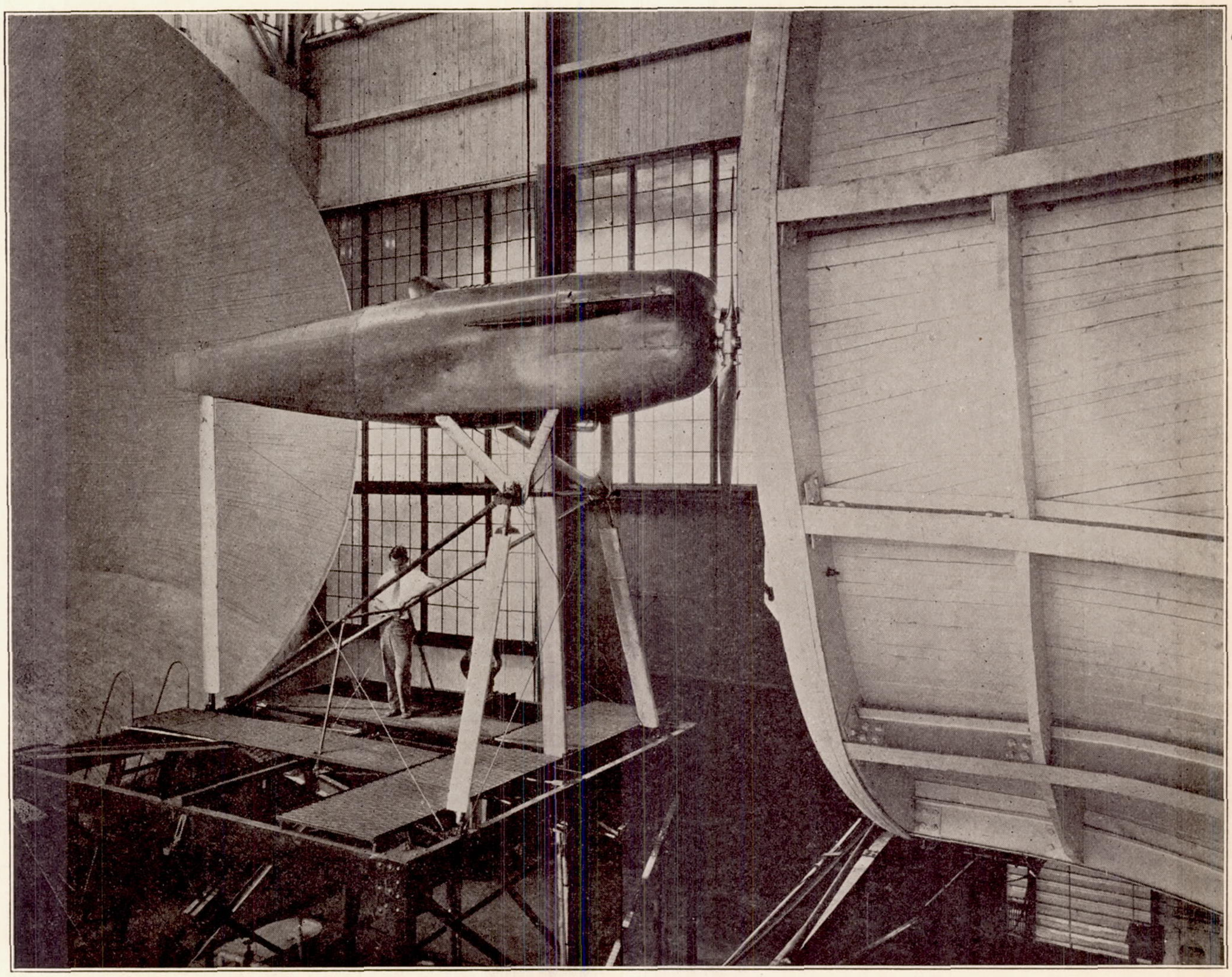


FIGURE 1.—Full-scale propeller and fuselage

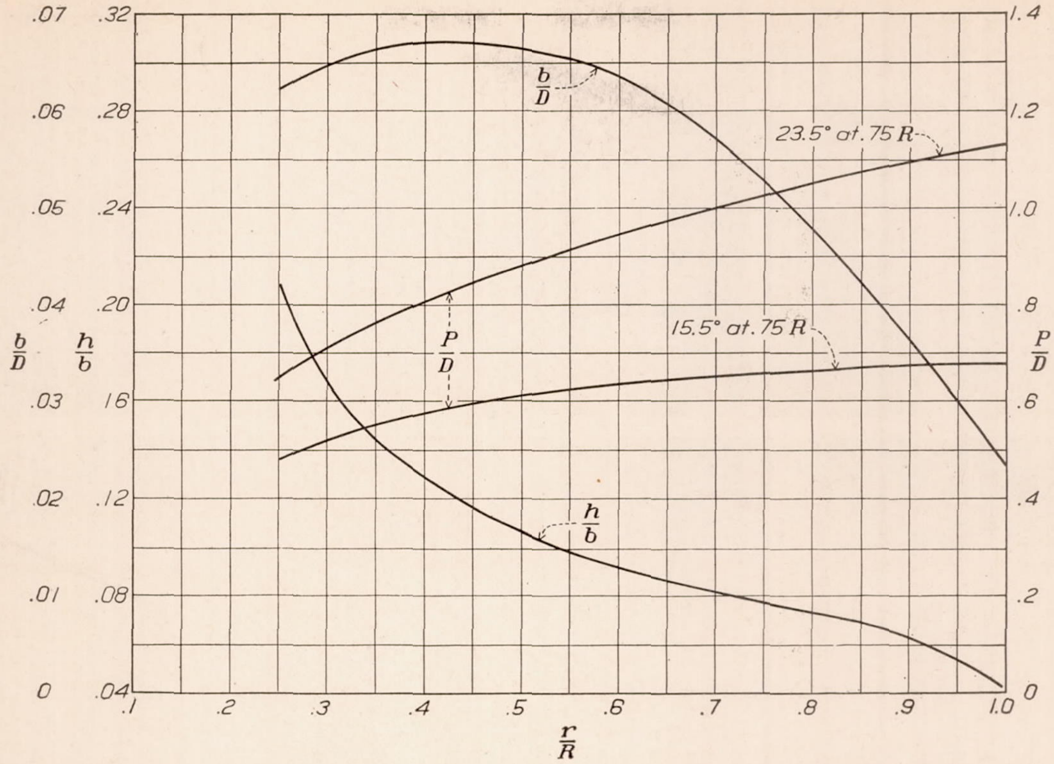


FIGURE 2.—Blade form curves. Propeller No. 4412. b=blade width; D=diameter of propeller; P=pitch; h=maximum blade thickness; R=radius of propellr; r=section radius

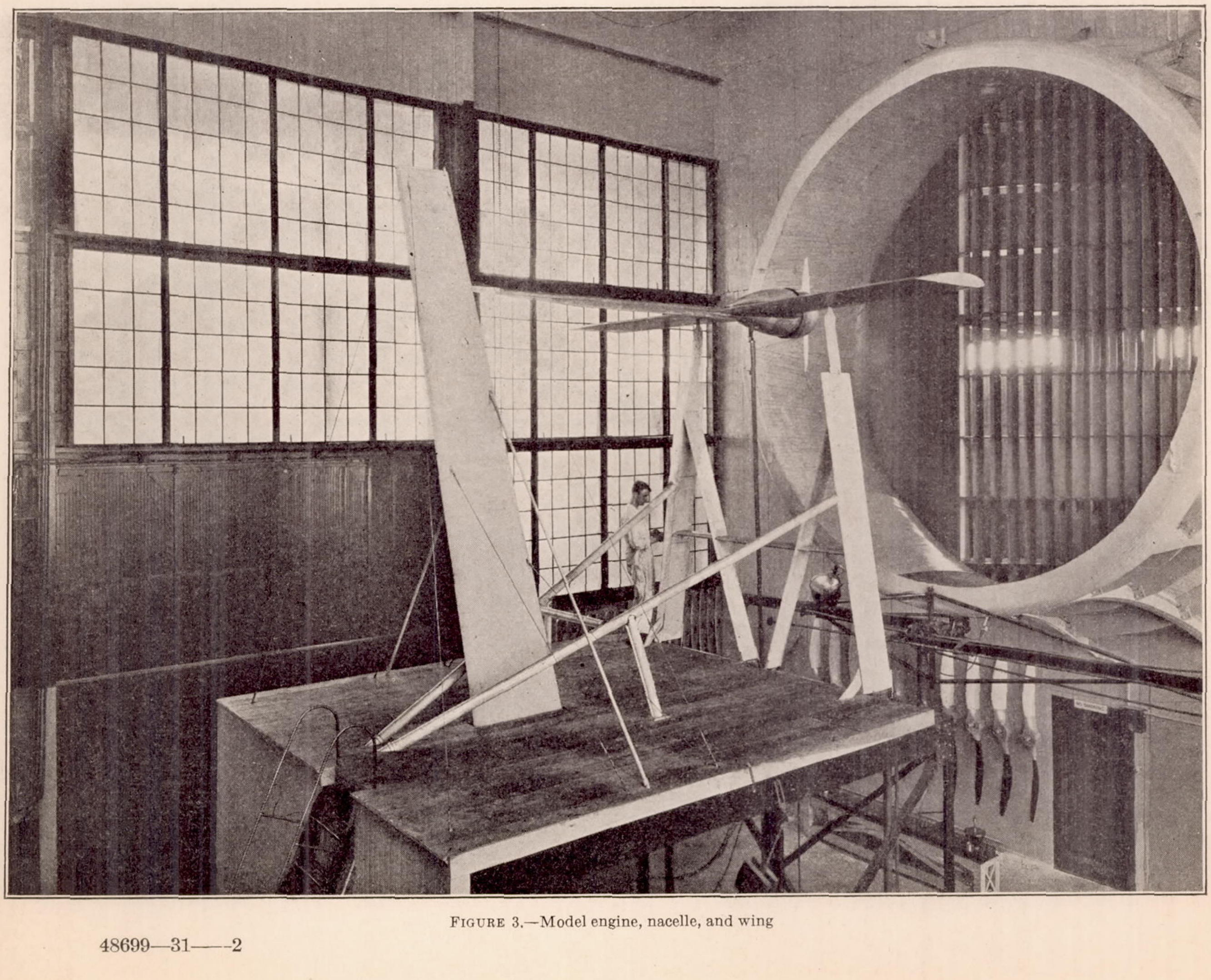
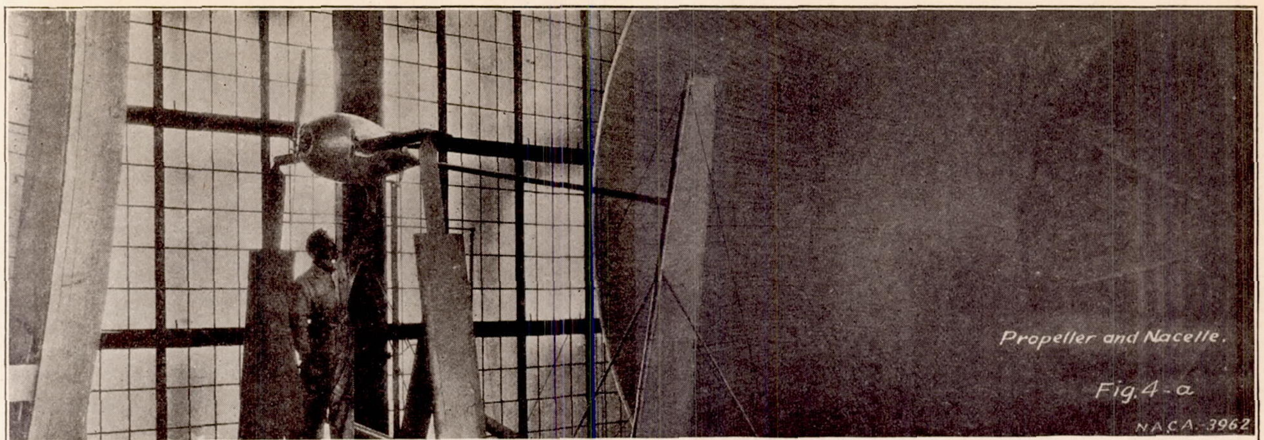
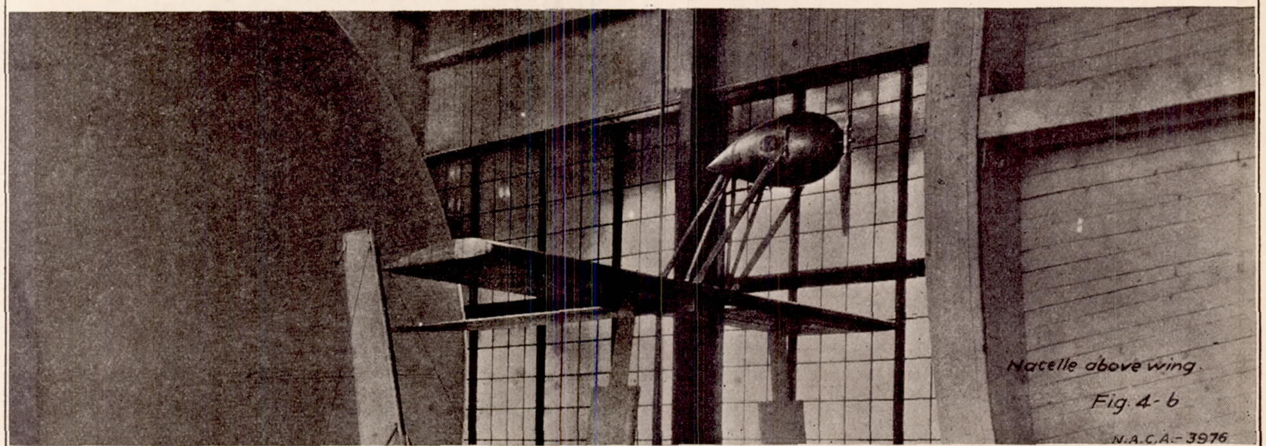
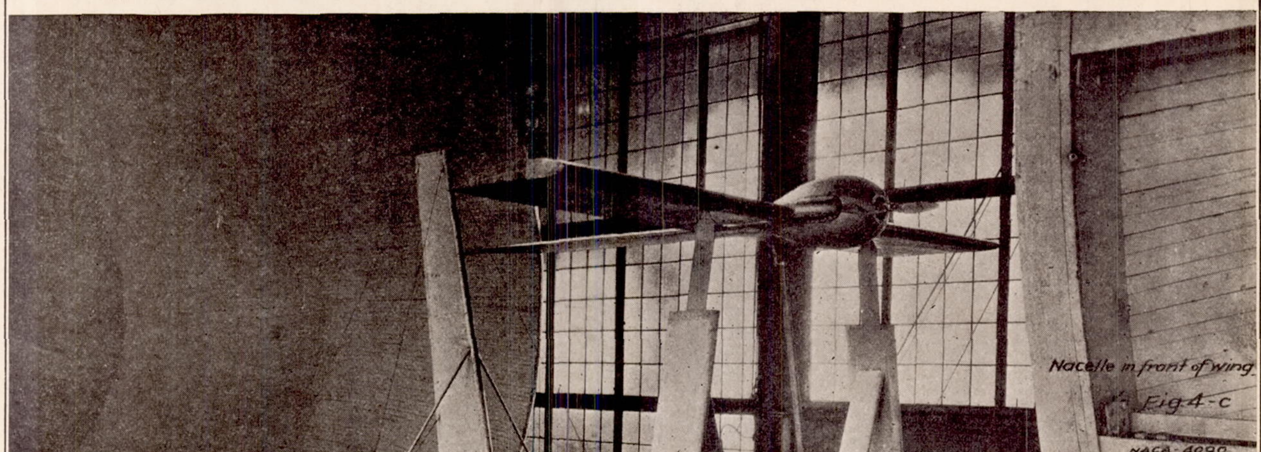
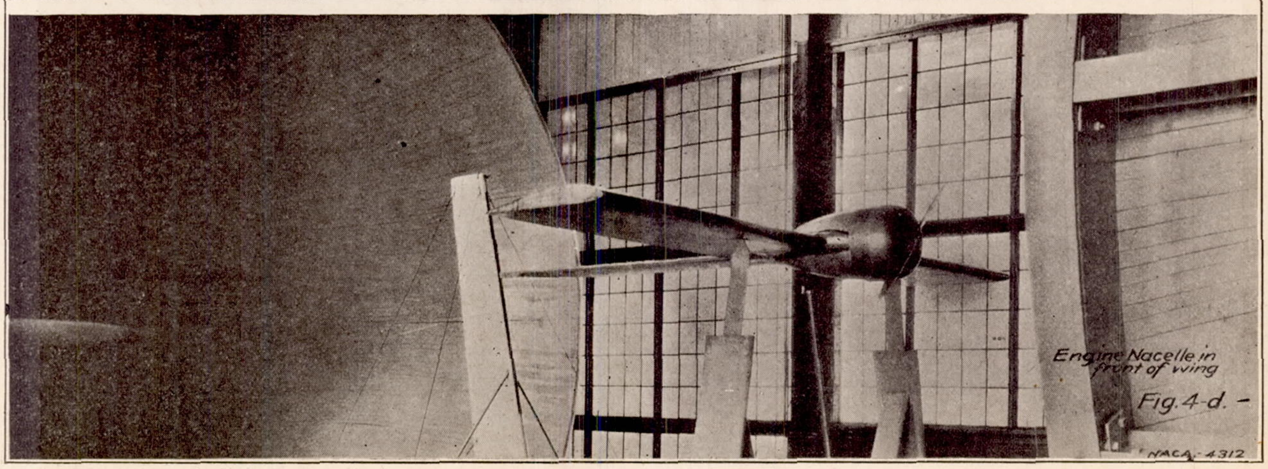


FIGURE 3.—Model engine, nacelle, and wing


Propeller and Nacelle.
Fig. 4-a
N.A.C.A.-3962


Nacelle above wing.
Fig. 4-b
N.A.C.A.-3976


Nacelle in front of wing
Fig. 4-c
NACA-4090


Engine Nacelle in front of wing
Fig. 4-d. -
NACA.-4312

wing (fig. 4b), and third in front of the wing (fig. 4c). Later dummy cylinders were fixed to the nacelle to simulate a Wright J–5 engine. The model engine was

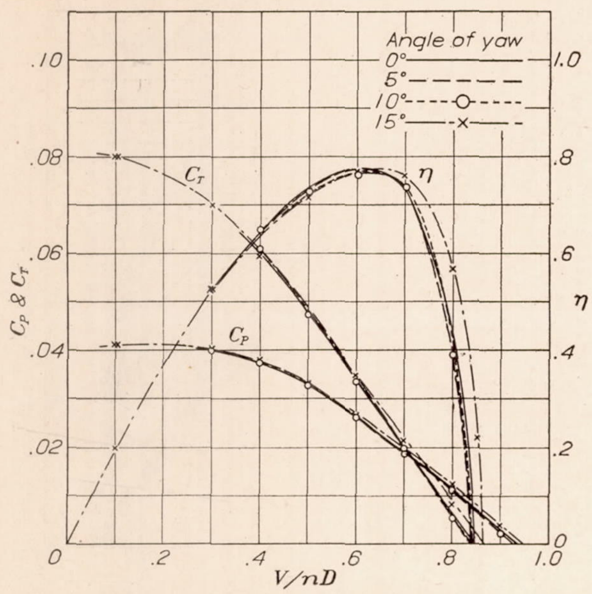


FIGURE 5.—Characteristics of propeller No. 4412, 15.5° at 0.75 *R*.; diam. 9 ft.

provided with an N. A. C. A. cowling. This arrangement (fig. 4d) was tested n the same position relative to the wing as that shown in Figure 4c. All the arrangements were tested at four propeller blade settings (12°, 17°, 22°, and 27° at 0.75 radius) and with the thrust line at five angles of pitch (−5°, 0°,

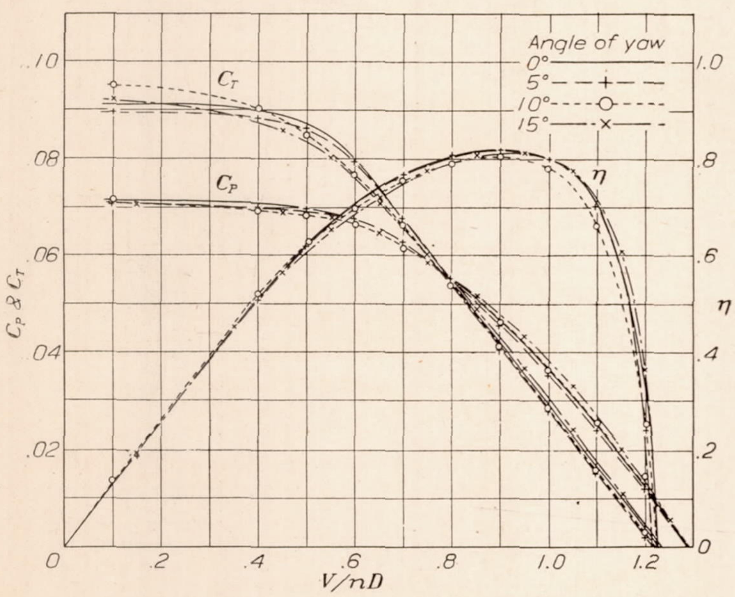


FIGURE 6.—Characteristics of propeller No. 4412, 23.5° at 0.75 *R;* diam. 9 ft.

+5°, +10°, and +15°) relative to the wind direction. The forces in the model tests were measured in the same manner as those in the full-scale tests, except that the torque of the motor was obtained from the calibration curve (armature current versus torque) previously determined.

For zero pitch or yaw, the resultant horizontal force on the propeller-body combination, as measured on the thrust balance, is equal to:

$$R = T - \Delta D - D$$

where T = propeller thrust (tension in propeller shaft),
D = drag of combination without propeller (at the same dynamic pressure q),
ΔD = increment of drag due to slipstream.

The effective thrust may be defined as

$$T - \Delta D = R + D$$

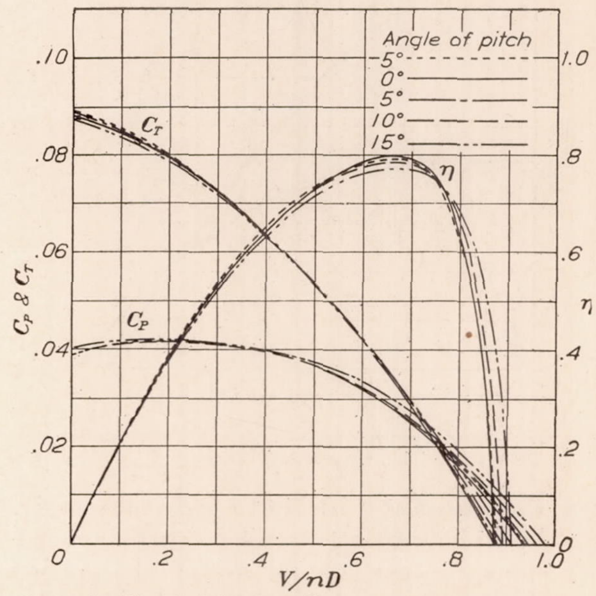


FIGURE 7.—Characteristics of propeller No. 4412; 4 ft. diam.; set 17° at 0.75 *R;* nacelle alone

RESULTS AND DISCUSSION

The data are reduced to the usual nondimenional coefficients of thrust, power, and propulsive efficiency:

$$\text{Thrust coefficient} = C_T = \frac{\text{effective thrust}}{\rho\, n^2\, D^4}$$

$$\text{Power coefficient} \quad = C_P = \frac{\text{input power}}{\rho\, n^3\, D^5}$$

$$\text{Propulsive efficiency} = \frac{\text{effective thrust} \times \text{velocity of advance}}{\text{input power}}$$

where ρ = mass density of the air,
n = revolutions per unit time,
D = diameter of propeller.

The observed data are given in Tables I and II for the full-scale tests.

The faired curves of these coefficients plotted against $\frac{V}{n\,D}$ are given in Figures 5 and 6. These curves show no consistent variation with the change in the angle of yaw. The change in the thrust and power coefficients is small and the greatest variation in the peak efficiency is only 2 per cent.

The results for the model propeller tests are given in Figures 7 to 10, inclusive. Only the curves for the 17° blade settings are presented, since these are repre-

sentative of the curves for all the blade settings. The tables of these data have not been included in this report, since they are soon to be published in a report on wing-nacelle-propeller tests.

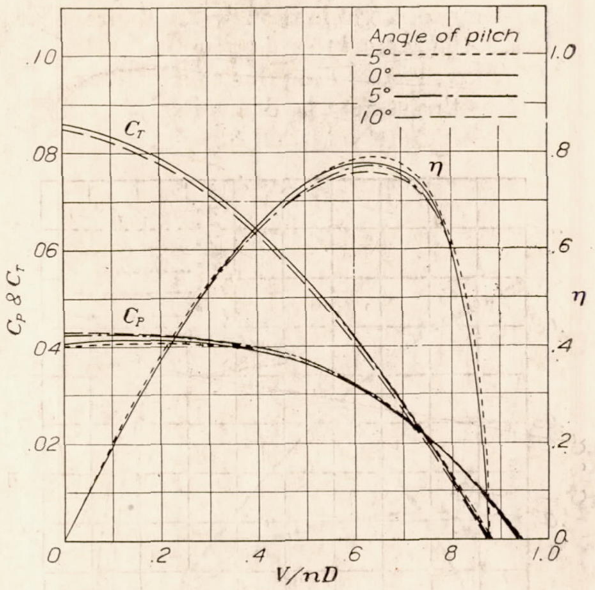


FIGURE 8.—Characteristics of propeller No. 4412; 4 ft. diam.; set 17° at 0.75 *R;* nacelle above wing

For the propeller with the nacelle alone (fig. 7) there is very little change in the characteristics of the propeller for the change in the angle of the thrust line. When the propeller and nacelle are placed above the

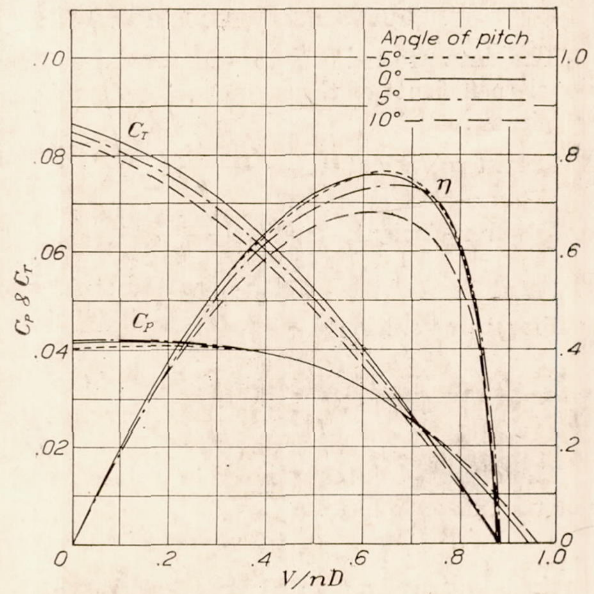


FIGURE 9.—Characteristics of propeller No. 4412; 4 ft. diam.; set 17° at 0.75 *R;* nacelle in front of wing

wing (fig. 8) there is a small but consistent decrease in effective thrust with increasing angle of pitch. Figures 9 and 10 show the results for the propeller and nacelle directly in front of the wing. For this condition the effective thrust decreases rapidly with increasing angle of the thrust line. For the model engine nacelle with the propeller set at 17° (fig. 10) the decrease in effective thrust at the $\frac{V}{nD}$ of peak effi-

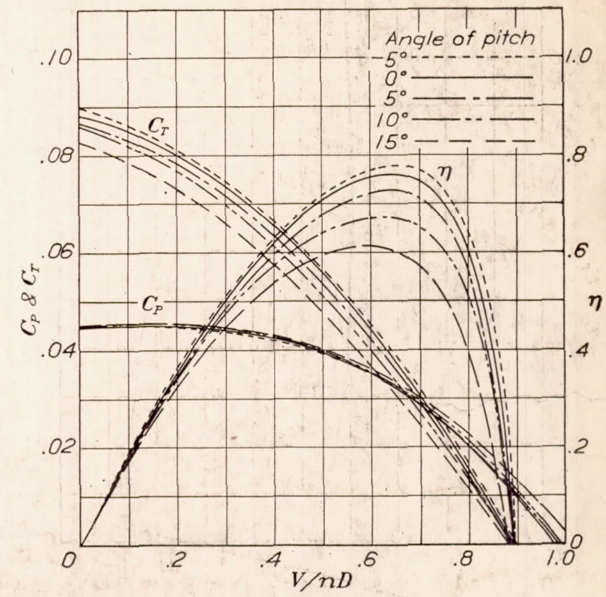


FIGURE 10.—Characteristics of propeller No. 4412; 4 ft. diam.; set 17° at 0.75 *R;* model engine nacelle in front of wing

ciency for a change in the angle of thrust line of 15° amounts to approximately 19 per cent.

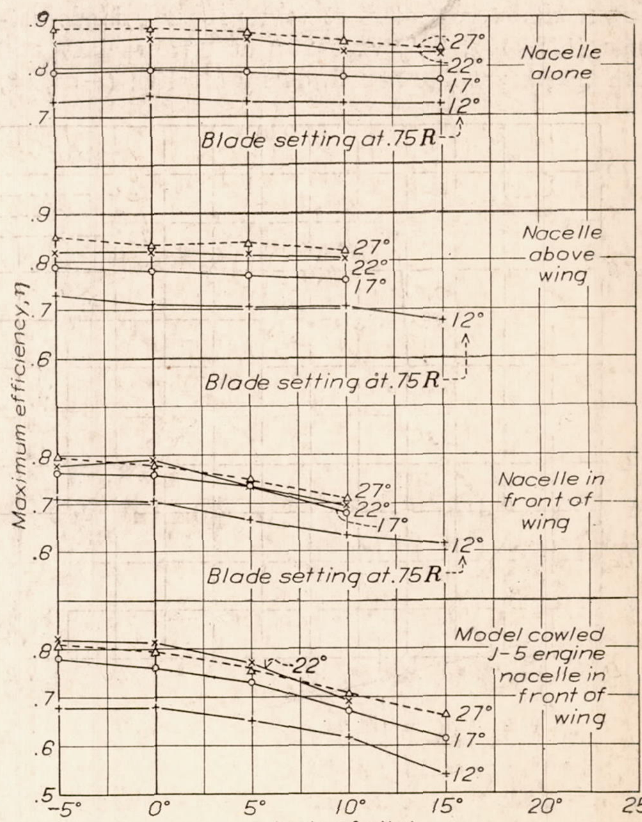


FIGURE 11.—Peak efficiencies against angles of pitch

In Figure 11 the peak efficiency, for the various blade settings and wing-nacelle combinations, has been

plotted against the angle of pitch. For the nacelle alone, the greatest change in peak efficiency for a 15° change in the angle of thrust line is 5 per cent. With the model cowled-engine nacelle, in front of the wing the greatest decrease in efficiency amounts to 15 per cent. The drop in peak efficiency is greater for the high blade settings than for the low, but the difference is small.

The results of the above tests indicate that the effect of small angles of yaw and pitch on the characteristics of a propeller is small provided there is no wing in the slipstream. However, if the propeller is working directly in front of a wing, the effective thrust and propulsive efficiency decrease rapidly with increasing angle of pitch.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *January 20, 1931.*

REFERENCES AND BIBLIOGRAPHY

1. Flachsbart, O., and Kröber, G.: Experimental Investigation of Aircraft Propellers Exposed to Oblique Air Currents. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, December 14, 1929. N. A. C. A. Technical Memorandum No. 562, 1930.
2. Wood, Donald H.: Full Scale Tests of Metal Propellers at High Tip Speeds. N. A. C. A. Technical Report No. 375, 1930.
3. Weick, Fred E., and Wood, Donald H.: The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. N. A. C. A. Technical Report No. 300, 1928.
4. Clarke, T. W. K.: Effect of Side Wind on a Propeller. British A. C. A., Reports and Memoranda No. 80, 1913.
5. Bramwell, F. H., Fage, A., Relf, E. F., and Bryant, L. W.: Experiments on Model Propellers at the National Physical Laboratory. British A. C. A., Reports and Memoranda No. 123, 1914.
6. Harris, R. G.: Forces on a Propeller Due to Sideslip. British A. C. A., Reports and Memoranda No. 427, 1918.

TABLE I
TEST RESULTS
PROPELLER 4412—23.5° AT 0.75R. 0° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002331	87. 0	1, 580	1, 058	906	0. 0854	0. 0696	0. 538	0. 659
. 002331	87. 0	1, 580	1, 056	904	. 0850	. 0696	. 538	. 656
. 002327	87. 0	1, 590	1, 059	873	. 0815	. 0687	. 535	. 635
. 002327	92. 1	1, 590	1, 056	884	. 0825	. 0687	. 566	. 680
. 002327	94. 7	1, 590	1, 060	878	. 0820	. 0690	. 583	. 692
. 002327	94. 7	1, 590	1, 058	877	. 0820	. 0687	. 583	. 695
. 002313	105. 0	1, 600	1, 060	845	. 0782	. 0685	. 640	. 731
. 002313	105. 0	1, 620	1, 057	840	. 0760	. 0667	. 634	. 722
. 002313	103. 9	1, 550	959	758	. 0749	. 0662	. 655	. 740
. 002313	103. 9	1, 550	957	759	. 0749	. 0662	. 655	. 740
. 002313	103. 5	1, 480	839	650	. 0703	. 0634	. 683	. 757
. 002313	103. 5	1, 480	840	649	. 0703	. 0634	. 683	. 757
. 002316	103. 0	1, 410	727	547	. 0651	. 0605	. 714	. 768
. 002316	103. 2	1, 410	728	545	. 0649	. 0605	. 717	. 769
. 002309	102. 8	1, 340	643	465	. 0616	. 0593	. 750	. 780
. 002309	102. 9	1, 350	642	464	. 0606	. 0584	. 746	. 775
. 002309	102. 8	1, 280	552	390	. 0567	. 0557	. 786	. 800
. 002309	102. 8	1, 270	554	389	. 0574	. 0569	. 791	. 799
. 002309	102. 8	1, 230	478	326	. 0512	. 0524	. 817	. 800
. 002309	102. 8	1, 220	477	324	. 0519	. 0532	. 823	. 801
. 002309	102. 0	1, 170	413	272	. 0473	. 0501	. 853	. 805
. 002309	102. 2	1, 170	412	271	. 0472	. 0501	. 855	. 805
. 002309	101. 6	1, 110	343	217	. 0419	. 0461	. 895	. 812
. 002309	101. 8	1, 100	342	215	. 0423	. 0468	. 905	. 817
. 002309	101. 8	1, 050	278	165	. 0356	. 0418	. 947	. 806
. 002309	101. 6	1, 050	278	165	. 0358	. 0418	. 956	. 820
. 002309	101. 6	1, 000	235	133	. 0316	. 0390	. 991	. 803
. 002309	101. 6	1, 010	235	132	. 0308	. 0382	. 984	. 794
. 002309	101. 4	950	169	86	. 0227	. 0311	1. 044	. 764
. 002309	101. 2	900	126	57	. 0167	. 0258	1. 10	. 712
. 002309	101. 1	860	77	25	. 00805	. 01722	1. 15	. 537
. 002301	101. 0	800	40	1	. 000372	. 0104	1. 233	. 0442
. 002301	101. 0	780	0	−29	−. 01135	0	1. 267	--------
. 002313	78. 5	1, 585	1, 058	926	. 0878	. 0700	. 485	. 608
. 002313	78. 9	1, 580	1, 051	922	. 0878	. 0698	. 489	. 615
. 002313	74. 3	1, 580	1, 056	930	. 0885	. 0702	. 460	. 580
. 002313	71. 1	1, 580	1, 053	930	. 0885	. 0700	. 441	. 557
. 002316	67. 3	1, 580	1, 056	936	. 0891	. 0702	. 417	. 529
. 002316	67. 0	1, 580	1, 056	937	. 0891	. 0702	. 415	. 526
. 002316	62. 8	1, 580	1, 062	939	. 0894	. 0703	. 389	. 493
. 002316	63. 0	1, 580	1, 060	940	. 0895	. 0704	. 390	. 496
. 002319	57. 4	1, 590	1, 065	948	. 0889	. 0695	. 353	. 451
. 002319	56. 4	1, 590	1, 061	946	. 0887	. 0693	. 347	. 445
. 002325	23. 3	1, 580	1, 038	950	. 0896	. 0705	. 1445	. 1838
. 002325	24. 2	1, 530	1, 056	945	. 0953	. 0744	. 1545	. 198

TABLE I—Continued
TEST RESULTS
PROPELLER 4412—23.5° AT 0.75R. 5° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002275	85. 8	1, 600	1, 036	899	0. 0846	0. 0681	0. 525	0. 652
. 002275	85. 8	1, 600	1, 036	898	. 0845	. 0681	. 525	. 652
. 002275	90. 6	1, 600	1, 042	882	. 0830	. 0683	. 554	. 673
. 002275	90. 5	1, 600	1, 040	882	. 0830	. 0683	. 553	. 672
. 002265	95. 5	1, 610	1, 041	860	. 0804	. 0679	. 580	. 687
. 002265	95. 6	1, 600	1, 040	861	. 0815	. 0687	. 585	. 694
. 002259	106. 5	1, 630	1, 040	825	. 0754	. 0664	. 640	. 724
. 002259	106. 0	1, 640	1, 037	821	. 0743	. 0655	. 632	. 717
. 002259	106. 2	1, 580	960	757	. 0735	. 0652	. 657	. 741
. 002259	106. 0	1, 580	959	757	. 0735	. 0650	. 657	. 744
. 002250	105. 8	1, 530	877	687	. 0717	. 0639	. 676	. 759
. 002250	105. 8	1, 530	878	685	. 0715	. 0639	. 676	. 757
. 002250	105. 0	1, 480	796	606	. 0675	. 0618	. 694	. 758
. 002250	105. 1	1, 470	791	607	. 0685	. 0621	. 700	. 772
. 002250	104. 9	1, 410	685	508	. 0623	. 0686	. 726	. 773
. 002250	104. 9	1, 400	683	508	. 0633	. 0593	. 732	. 781
. 002250	104. 9	1, 340	611	438	. 0596	. 0580	. 765	. 786
. 002250	104. 5	1, 340	611	437	. 0593	. 0580	. 763	. 780
. 002250	104. 2	1, 270	510	354	. 0537	. 0538	. 802	. 800
. 002250	104. 0	1, 260	508	353	. 0543	. 0544	. 807	. 806
. 002254	104. 0	1, 220	438	297	. 0485	. 0500	. 833	. 807
. 002254	103. 8	1, 220	439	295	. 0482	. 0501	. 831	. 800
. 002254	103. 8	1, 160	378	243	. 0440	. 0478	. 875	. 806
. 002254	103. 2	1, 170	382	249	. 0442	. 0475	. 863	. 802
. 002246	103. 4	1, 100	311	194	. 0391	. 0439	. 920	. 820
. 002246	103. 4	1, 100	311	194	. 0391	. 0439	. 920	. 820
. 002246	103. 4	1, 040	248	148	. 0334	. 0392	. 972	. 829
. 002246	103. 0	1, 040	246	144	. 0325	. 0388	. 968	. 810
. 002246	103. 2	970	166	86	. 0223	. 0301	1. 04	. 770
. 002246	103. 2	930	131	63	. 01775	. 0258	1. 083	. 746
. 002246	103. 2	880	91	35	. 01104	. 0200	1. 146	. 633
. 002246	103. 0	820	31	−4	−. 00145	. 00786	1. 23	--------
. 002256	80. 3	1, 590	1, 033	909	. 0873	. 0694	. 494	. 621
. 002256	79. 8	1, 600	1, 031	910	. 0865	. 0682	. 488	. 619
. 002256	74. 8	1, 600	1, 037	919	. 0872	. 0686	. 457	. 580
. 002256	74. 8	1, 590	1, 036	918	. 0883	. 0695	. 460	. 584
. 002259	69. 4	1, 600	1, 040	922	. 0875	. 0687	. 424	. 540
. 002259	69. 4	1, 600	1, 037	922	. 0875	. 0685	. 424	. 541
. 002262	65. 2	1, 610	1, 041	927	. 0870	. 0707	. 396	. 487
. 002262	63. 5	1, 600	1, 040	925	. 0880	. 0687	. 388	. 497
. 002262	59. 0	1, 600	1, 045	929	. 0882	. 0689	. 361	. 462
. 002262	59. 3	1, 600	1, 044	928	. 0881	. 0689	. 362	. 463
. 002262	56. 1	1, 590	1, 046	931	. 0894	. 0698	. 346	. 443
. 002262	56. 1	1, 590	1, 045	932	. 0895	. 0698	. 346	. 444
. 002267	23. 8	1, 590	1, 051	906	. 0866	. 0703	. 1465	. 181
. 002267	24. 4	1, 550	1, 045	900	. 0908	. 0734	. 154	. 191

TABLE I—Continued
TEST RESULTS
PROPELLER 4412—23.5° AT 0.75R. 10° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002233	83. 8	1, 590	1, 012	873	0. 0848	0. 0686	0. 516	0. 638
. 002233	83. 8	1, 590	1, 010	873	. 0848	. 0686	. 516	. 638
. 002230	88. 4	1, 600	1, 012	855	. 0821	. 0678	. 540	. 654
. 002230	89. 4	1, 590	1, 012	858	. 0835	. 0685	. 556	. 670
. 002230	94. 0	1, 605	1, 013	840	. 0803	. 0676	. 572	. 679
. 002230	94. 6	1, 620	1, 011	834	. 0781	. 0662	. 571	. 674
. 002217	103. 8	1, 630	1, 011	801	. 0746	. 0659	. 603	. 683
. 002217	102. 8	1, 610	1, 009	801	. 0766	. 0673	. 624	. 710
. 002217	102. 8	1, 560	922	733	. 0747	. 0654	. 644	. 736
. 002217	102. 6	1, 570	923	729	. 0730	. 0647	. 638	. 719
. 002217	102. 9	1, 520	855	668	. 0715	. 0640	. 660	. 736
. 002217	102. 8	1, 510	853	666	. 0723	. 0646	. 665	. 743
. 002217	102. 8	1, 460	772	589	. 0684	. 0627	. 687	. 750
. 002217	102. 8	1, 470	773	589	. 0674	. 0616	. 683	. 747
. 002217	102. 5	1, 410	708	525	. 0655	. 0613	. 710	. 756
. 002217	102. 5	1, 410	705	526	. 0656	. 0612	. 710	. 762
. 002217	101. 9	1, 350	635	460	. 0624	. 0601	. 736	. 765
. 002217	101. 9	1, 350	632	458	. 0622	. 0599	. 736	. 765
. 002217	101. 7	1, 300	544	382	. 0560	. 0555	. 765	. 772
. 002217	101. 7	1, 290	539	381	. 0567	. 0556	. 771	. 785
. 002213	102. 0	1, 240	487	337	. 0544	. 0536	. 805	. 816
. 002213	102. 0	1, 250	487	338	. 0537	. 0528	. 797	. 810
. 002213	101. 2	1, 210	436	294	. 0498	. 0516	. 817	. 790
. 002213	101. 2	1, 210	436	295	. 050	. 0516	. 817	. 791
. 002213	101. 0	1, 160	389	256	. 0472	. 0501	. 851	. 802
. 002213	101. 0	1, 165	389	256	. 0468	. 0497	. 848	. 800
. 002213	100. 7	1, 110	330	208	. 0418	. 0462	. 885	. 802
. 002213	100. 7	1, 110	325	205	. 0413	. 0455	. 885	. 802
. 002213	100. 7	1, 070	291	179	. 0388	. 0441	. 920	. 809
. 002213	100. 7	1, 070	290	177	. 0383	. 0440	. 920	. 801
. 002213	100. 4	1, 020	245	142	. 0338	. 0409	. 964	. 797
. 002213	100. 4	1, 020	247	144	. 0343	. 0411	. 964	. 804
. 002213	100. 5	960	177	92	. 0247	. 0332	1. 023	. 764
. 002213	100. 0	890	108	48	. 015	. 0236	1. 10	. 70
. 002213	100. 0	850	83	26	. 00891	. 01981	1. 15	. 517
. 002213	100. 0	800	46	6	. 00232	. 0124	1. 222	. 230
. 002222	97. 3	1, 600	1, 004	886	. 0856	. 0677	. 485	. 613
. 002222	78. 8	1, 600	1, 005	870	. 0841	. 0677	. 482	. 599
. 002226	73. 0	1, 590	1, 013	909	. 0889	. 0689	. 450	. 580
. 002226	73. 0	1, 590	1, 009	905	. 0885	. 0687	. 450	. 580
. 002226	67. 6	1, 600	1, 016	927	. 0892	. 0684	. 413	. 539
. 002228	66. 7	1, 600	1, 013	927	. 0892	. 0682	. 408	. 534
. 002228	62. 8	1, 610	1, 019	951	. 0905	. 0675	. 382	. 512
. 002228	61. 9	1, 610	1, 017	948	. 0903	. 0675	. 376	. 503
. 002228	57. 9	1, 600	1, 021	961	. 0925	. 0686	. 354	. 477
. 002228	57. 9	1, 605	1, 023	957	. 0917	. 0684	. 353	. 473
. 002226	21. 75	1, 580	1, 024	944	. 0930	. 0705	. 1347	. 1777
. 002226	22. 25	1, 540	1, 017	933	. 0970	. 0736	. 1412	. 1860

TABLE I—Continued
TEST RESULTS
PROPELLER 4412—23.5° AT 0.75R. 15° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002226	85. 2	1, 590	998	1, 364	0. 0820	0. 0678	0. 524	0. 634
. 002226	85. 2	1, 590	994	1, 360	. 0815	. 0676	. 524	. 632
. 002226	89. 2	1, 590	1, 000	1, 335	. 0807	. 0681	. 548	. 649
. 002226	88. 5	1, 590	997	1, 338	. 0807	. 0678	. 544	. 647
. 002223	93. 8	1, 600	998	1, 298	. 0780	. 0670	. 574	. 668
. 002223	93. 0	1, 600	995	1, 305	. 0784	. 0668	. 568	. 667
. 002223	95. 3	1, 600	998	1, 289	. 0778	. 0670	. 583	. 677
. 002223	95. 5	1, 590	996	1, 281	. 0780	. 0679	. 587	. 675
. 002213	103. 0	1, 620	997	1, 218	. 0728	. 0658	. 622	. 689
. 002213	102. 8	1, 600	997	1, 219	. 0745	. 0674	. 629	. 695
. 002213	102. 2	1, 540	894	1, 137	. 0715	. 0652	. 650	. 713
. 002213	102. 2	1, 540	893	1, 141	. 0719	. 0652	. 650	. 716
. 002213	102. 2	1, 480	801	1, 057	. 0684	. 0634	. 676	. 730
. 002213	102. 2	1, 470	800	1, 058	. 0694	. 0640	. 680	. 737
. 002213	101. 5	1, 410	701	974	. 0647	. 0610	. 705	. 748
. 002213	101. 3	1, 410	701	976	. 0647	. 0610	. 704	. 746
. 002213	101. 3	1, 340	606	890	. 0599	. 0583	. 740	. 761
. 002213	101. 3	1, 335	605	891	. 0603	. 0586	. 742	. 763
. 002213	101. 3	1, 280	531	830	. 0565	. 0560	. 775	. 782
. 002213	101. 3	1, 270	530	828	. 0570	. 0568	. 780	. 782
. 002213	101. 1	1, 215	457	771	. 0526	. 0535	. 815	. 801
. 002213	101. 1	1, 220	460	772	. 0523	. 0535	. 811	. 794
. 002213	101. 1	1, 160	395	718	. 0479	. 0508	. 853	. 804
. 002213	101. 1	1, 160	395	716	. 0476	. 0508	. 853	. 800
. 002205	101. 0	1, 100	341	674	. 0441	. 0496	. 899	. 810
. 002205	101. 0	1, 110	342	676	. 0437	. 0481	. 890	. 808
. 002205	100. 8	1, 060	293	640	. 0399	. 0453	. 930	. 820
. 002205	101. 0	1, 060	290	634	. 0386	. 0449	. 932	. 801
. 002205	100. 7	1, 000	239	596	. 0336	. 0416	. 985	. 796
. 002205	100. 8	1, 010	241	600	. 0342	. 0411	. 975	. 812
. 002205	100. 5	960	149	538	. 0224	. 0306	1. 068	. 781
. 002205	100. 4	860	90	499	. 0121	. 0211	1. 140	. 654
. 002205	99. 6	800	38	470	. 00195	. 01033	1. 220	. 229
. 002221	76. 5	1, 585	999	1, 426	. 0857	. 0687	. 472	. 589
. 002221	76. 5	1, 580	998	1, 424	. 0859	. 0693	. 474	. 587
. 002224	72. 3	1, 590	1, 007	1, 453	. 0864	. 0683	. 445	. 562
. 002224	71. 5	1, 595	1, 005	1, 457	. 0861	. 0681	. 438	. 554
. 002224	67. 0	1, 595	1, 009	1, 487	. 0878	. 0683	. 411	. 529
. 002224	66. 3	1, 600	1, 007	1, 482	. 0864	. 0672	. 405	. 520
. 002228	63. 6	1, 610	1, 013	1, 513	. 0873	. 0670	. 387	. 509
. 002228	61. 9	1, 600	1, 009	1, 513	. 0880	. 0673	. 378	. 494
. 002252	58. 0	1, 605	1, 014	1, 537	. 0885	. 0676	. 353	. 461
. 002252	57. 7	1, 600	1, 012	1, 529	. 0882	. 0680	. 353	. 458
. 002257	17. 86	1, 520	1, 019	1, 611	. 0981	. 0756	. 1145	. 1486
. 002257	17. 86	1, 525	1, 015	1, 612	. 0970	. 0749	. 1149	. 149

TABLE II

TEST RESULTS

PROPELLER 4412—15.5° AT 0.75*R*. 0° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002310	83. 6	1, 890	789	866	0. 0576	0. 0366	0. 433	0. 681
. 002310	84. 1	1, 890	789	870	. 0579	. 0366	. 435	. 688
. 002310	88. 6	1, 890	768	826	. 0550	. 0356	. 458	. 708
. 002310	88. 0	1, 900	768	826	. 0544	. 0352	. 454	. 701
. 002307	93. 7	1, 890	727	756	. 0505	. 0338	. 485	. 725
. 002307	93. 5	1, 890	731	761	. 0508	. 0340	. 484	. 723
. 002304	102. 8	1, 890	669	658	. 0439	. 0311	. 533	. 751
. 002304	102. 8	1, 890	674	662	. 0441	. 0313	. 531	. 750
. 002304	102. 4	1, 800	571	545	. 0401	. 0293	. 557	. 764
. 002304	101. 5	1, 810	573	550	. 0399	. 0290	. 549	. 755
. 002304	101. 2	1, 700	463	426	. 0351	. 0266	. 582	. 769
. 002304	101. 2	1, 700	463	425	. 0350	. 0266	. 582	. 766
. 002297	101. 0	1, 590	370	318	. 0300	. 0244	. 621	. 765
. 002297	101. 2	1, 600	372	320	. 0299	. 0242	. 620	. 766
. 002297	101. 0	1, 495	291	236	. 0252	. 0217	. 660	. 764
. 002297	100. 3	1, 420	236	173	. 0206	. 01952	. 691	. 730
. 002297	100. 0	1, 310	160	96	. 01338	. 01552	. 746	. 643
. 002297	99. 8	1, 190	83	18	. 00304	. 00976	. 820	. 256
. 002297	99. 0	1, 090	24	−40	−. 00805	. 0337	. 886	--------
. 002309	76. 6	1, 890	814	923	. 0613	. 0378	. 397	. 644
. 002309	76. 9	1, 900	816	919	. 0604	. 0375	. 397	. 638
. 002309	72. 0	1, 880	810	925	. 0621	. 0379	. 375	. 615
. 002309	72. 0	1, 880	808	925	. 0621	. 0378	. 375	. 616
. 002309	66. 7	1, 885	836	946	. 0632	. 0389	. 346	. 562
. 002309	66. 7	1, 880	837	953	. 0640	. 0392	. 347	. 566
. 002312	61. 2	1, 890	859	992	. 0659	. 0398	. 317	. 525
. 002312	61. 2	1, 890	860	994	. 0660	. 0399	. 317	. 525

TABLE II—Continued

TEST RESULTS

PROPELLER 4412—15.5° AT 0.75*R*. 5° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002274	88. 8	1, 890	743	1, 360	0. 0537	0. 0352	0. 460	0. 701
. 002774	88. 8	1, 890	744	1, 360	. 0537	. 0352	. 460	. 701
. 002274	94. 6	1, 880	702	1, 273	. 0495	. 0336	. 493	. 726
. 002274	93. 0	1, 880	708	1, 290	. 0503	. 0338	. 484	. 720
. 002274	96. 1	1, 870	680	1, 237	. 0478	. 0328	. 503	. 733
. 002274	95. 7	1, 870	685	1, 245	. 0483	. 0330	. 501	. 734
. 002261	105. 5	1, 890	656	1, 140	. 0427	. 0311	. 546	. 750
. 002261	105. 5	1, 900	654	1, 145	. 0426	. 0307	. 543	. 754
. 002261	105. 5	1, 820	566	1, 047	. 0392	. 0289	. 567	. 770
. 002261	105. 5	1, 820	565	1, 044	. 0390	. 0289	. 567	. 766
. 002261	105. 3	1, 705	447	903	. 0326	. 0260	. 604	. 758
. 002261	104. 0	1, 705	448	928	. 0343	. 0261	. 596	. 784
. 002280	76. 0	1, 870	797	1, 505	. 0623	. 0384	. 398	. 646
. 002280	75. 0	1, 880	799	1, 504	. 0615	. 0380	. 390	. 631
. 002280	82. 0	1, 900	795	1, 459	. 0586	. 0370	. 422	. 670
. 002280	82. 0	1, 890	793	1, 461	. 0593	. 0372	. 424	. 676
. 002261	105. 7	1, 620	364	828	. 0293	. 0235	. 637	. 795
. 002261	105. 0	1, 510	268	715	. 0214	. 01995	. 680	. 730
. 002261	104. 8	1, 400	188	633	. 01465	. 01626	. 732	. 660
. 002261	104. 8	1, 300	123	564	. 00705	. 01230	. 787	. 451
. 002256	104. 5	1, 190	48	502	−. 00258	. 00575	. 859	--------
. 002268	70. 3	1, 880	798	1, 536	. 0623	. 0381	. 366	. 607
. 002268	70. 3	1, 870	801	1, 535	. 0638	. 0386	. 368	. 608
. 002271	65. 1	1, 870	807	1, 561	. 0648	. 0388	. 341	. 570
. 002271	64. 8	1, 870	817	1, 563	. 0649	. 0394	. 339	. 558
. 002271	60. 7	1, 880	812	1, 586	. 0652	. 0388	. 316	. 531
. 002271	60. 7	1, 870	813	1, 587	. 0660	. 0391	. 317	. 535

TABLE II—Continued

TEST RESULTS

PROPELLER 4412—15.5° AT 0.75*R*. 10° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 002288	87. 4	1, 890	771	820	0. 0551	0. 0362	0. 452	0. 688
. 002288	86. 7	1, 890	771	822	. 0552	. 0362	. 448	. 684
. 002285	91. 5	1, 890	730	757	. 0509	. 0342	. 473	. 705
. 002285	91. 5	1, 890	731	761	. 0511	. 0344	. 473	. 704
. 002277	95. 6	1, 880	700	711	. 0486	. 0333	. 498	. 726
. 002277	95. 6	1, 880	700	712	. 0487	. 0333	. 498	. 728
. 002271	105. 0	1, 900	656	630	. 0422	. 0307	. 540	. 743
. 002271	104. 9	1, 900	656	639	. 0427	. 0307	. 540	. 751
. 002271	104. 8	1, 800	550	513	. 0383	. 0286	. 570	. 763
. 002271	104. 8	1, 810	550	508	. 0374	. 0284	. 567	. 746
. 002271	103. 5	1, 695	444	394	. 0332	. 0261	. 597	. 759
. 002271	103. 5	1, 690	442	395	. 0334	. 0261	. 599	. 766
. 002264	103. 8	1, 590	351	293	. 0280	. 0234	. 639	. 764
. 002264	103. 8	1, 590	352	293	. 0280	. 0235	. 639	. 762
. 002264	103. 4	1, 470	256	191	. 0214	. 0200	. 689	. 736
. 002267	102. 5	1, 400	201	139	. 01720	. 01736	. 715	. 709
. 002267	102. 3	1, 300	135	72	. 01032	. 01350	. 770	. 589
. 002267	102. 0	1, 220	84	19	. 00309	. 00952	. 817	. 265
. 002267	102. 0	1, 120	23	−38	−. 00734	. 00309	. 890	--------
. 002276	78. 2	1, 890	789	881	. 0595	. 0372	. 404	. 645
. 002276	78. 0	1, 890	787	880	. 0594	. 0370	. 403	. 646
. 002279	73. 7	1, 890	810	929	. 0627	. 0382	. 381	. 625
. 002279	73. 0	1, 890	810	935	. 0632	. 0382	. 378	. 626
. 002279	67. 4	1, 890	827	984	. 0665	. 0389	. 348	. 595
. 002279	67. 4	1, 890	830	996	. 0673	. 0390	. 348	. 600
. 002282	61. 7	1, 870	835	1, 020	. 0700	. 0401	. 323	. 564
. 002282	62. 1	1, 880	832	1, 023	. 0696	. 0395	. 324	. 571

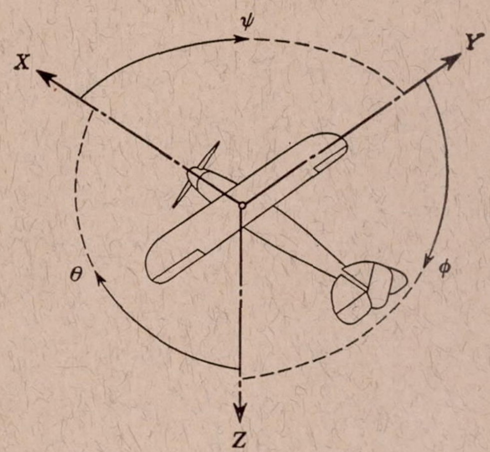
TABLE II—Continued

TEST RESULTS

PROPELLER 4412—15.5° AT 0.75*R*. 15° YAW

ρ	V m. p. h.	N r. p. m.	Q lb. ft.	T lb.	C_T	C_P	$\frac{V}{nD}$	η
0. 00231	89. 0	1, 900	773	804	0. 0540	0. 0363	0. 458	0. 682
. 00231	89. 0	1, 900	773	806	. 0542	. 0363	. 458	. 684
. 00231	92. 6	1, 890	728	747	. 0507	. 0346	. 479	. 703
. 00231	92. 4	1, 890	727	748	. 0508	. 0345	. 478	. 705
. 002307	95. 5	1, 890	692	698	. 0477	. 0330	. 494	. 714
. 002307	94. 2	1, 880	692	709	. 0490	. 0334	. 490	. 719
. 002304	103. 9	1, 890	653	625	. 0428	. 0312	. 537	. 737
. 002304	103. 7	1, 890	659	632	. 0432	. 0314	. 536	. 737
. 002304	103. 6	1, 810	560	534	. 0398	. 0291	. 560	. 766
. 002304	103. 3	1, 810	560	532	. 0396	. 0291	. 558	. 760
. 002304	102. 9	1, 690	442	395	. 0337	. 0264	. 596	. 761
. 002304	103. 0	1, 690	442	395	. 0337	. 0264	. 596	. 761
. 002297	103. 0	1, 600	364	311	. 0298	. 0244	. 630	. 770
. 002297	103. 0	1, 600	367	312	. 0299	. 0246	. 630	. 765
. 002297	102. 6	1, 500	292	235	. 0256	. 0225	. 669	. 769
. 002297	102. 1	1, 410	232	173	. 0213	. 0200	. 708	. 755
. 002297	101. 9	1, 300	150	91	. 0132	. 0152	. 766	. 665
. 002297	101. 6	1, 210	94	37	. 0062	. 0110	. 821	. 462
. 002297	101. 3	1, 100	27	−25	−. 00507	. 00381	. 901	--------
. 002309	81. 2	1, 890	778	842	. 0575	. 0371	. 420	. 650
. 002309	81. 4	1, 890	776	836	. 0571	. 0370	. 421	. 650
. 002309	75. 9	1, 890	808	899	. 0617	. 0385	. 393	. 627
. 002309	75. 8	1, 890	809	893	. 0610	. 0385	. 392	. 620
. 002309	71. 4	1, 890	820	926	. 0633	. 0391	. 369	. 597
. 002309	71. 1	1, 900	824	929	. 0635	. 0389	. 366	. 597
. 002312	63. 8	1, 880	826	973	. 0672	. 0398	. 332	. 560
. 002312	63. 9	1, 890	826	976	. 0666	. 0391	. 331	. 565
. 002312	59. 5	1, 880	831	999	. 0690	. 0400	. 310	. 535
. 002312	59. 6	1, 880	831	1, 001	. 0691	. 0400	. 310	. 536
. 002312	58. 3	1, 880	833	1, 011	. 0699	. 0401	. 303	. 529
. 002312	55. 8	1, 880	836	1, 022	. 0706	. 0402	. 290	. 510
. 002312	17. 80	1, 880	871	1, 164	. 0798	. 0418	. 0926	. 177
. 002312	18. 36	1, 890	871	1, 167	. 0800	. 0415	. 0950	. 183

U. S. GOVERNMENT PRINTING OFFICE: 1931



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	ϕ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	ψ	w	r

Absolute coefficients of moment

$$C_l=\frac{L}{qbS} \qquad C_m=\frac{M}{qcS} \qquad C_n=\frac{N}{qbS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p, Geometric pitch.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slipstream velocity.
T, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2 D^4}$
Q, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2 D^5}$
P, Power, absolute coefficient $C_P=\frac{P}{\rho n^3 D^5}$.
C_s, Speed power coefficient $=\sqrt[5]{\frac{\rho V^5}{P n^2}}$.
η, Efficiency.
n, Revolutions per second, r. p. s.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.
1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.